Multidisciplinary Analysis of a Hypersonic Engine

ISTAR Flowpath

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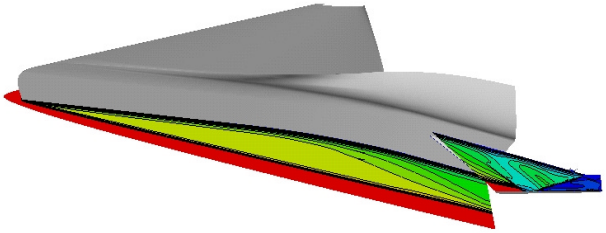
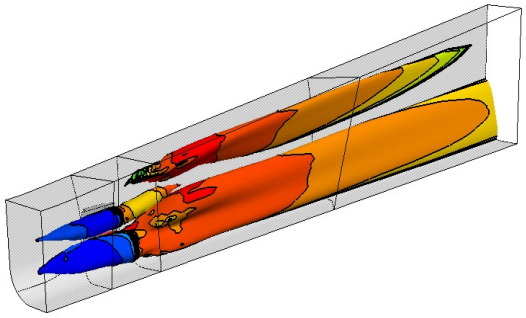
Outline

- **Overview & Motivation**
- **Description of Component Simulations**
- **Consistent Multidisciplinary Solutions**
- **Code Coupling Issues**
- **Benefits & Costs of MD Analysis**

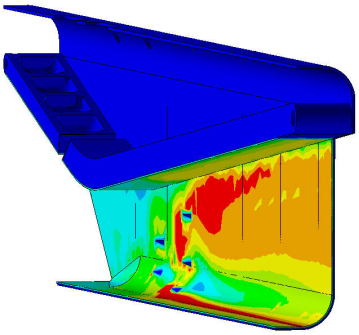
Multidisciplinary High Fidelity Analysis by Coupling Simulations



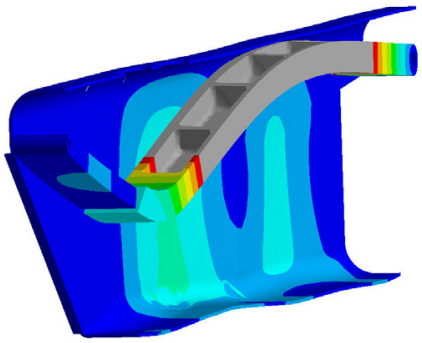
Aerodynamic Analysis



Combustion Analysis



Thermal Solid Analysis



Structural Analysis

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ISTAR Multidisciplinary Simulation: Objectives

- **Develop high fidelity tools that can influence ISTAR design**
- **In particular, tools for coupling Fluid-Thermal-Structural simulations**
- **RBCC/TBCC designers carefully balance aerodynamic, thermal, weight, & structural considerations; consistent multidisciplinary solutions reveal details (at modest cost)**
- **At Scram mode design point, simulations give details of inlet & combustor performance, thermal loads, structural deflections**

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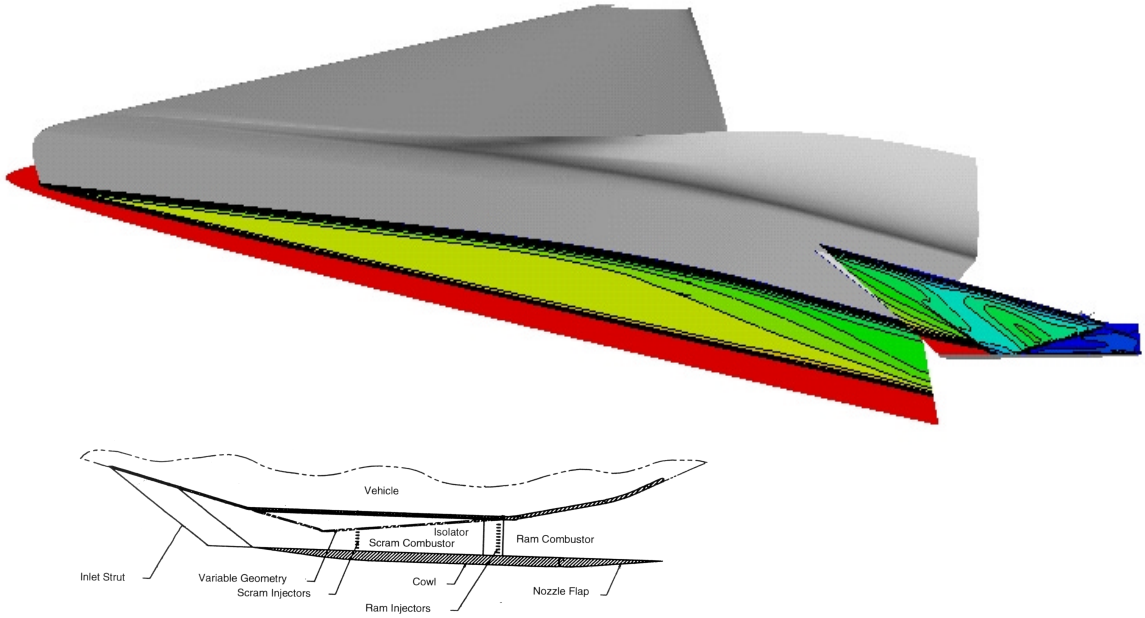
Approach Flow: Mach Contours



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Approach Solution

- **Full Navier-Stokes solution using *Overflow*.**
- **Simulation includes forebody, canard, & engine inlet—only forebody geometry that influences engine inflow**
- **Chimera five block structured grid with 9×10^5 cells.**
- **k-ω turbulence model with low-Reynolds number form—no compressibility correction**
- **Equilibrium chemistry**
- **Sets Combustor inflow**
- **Yields heat & pressure loads for thermal & structural analysis**

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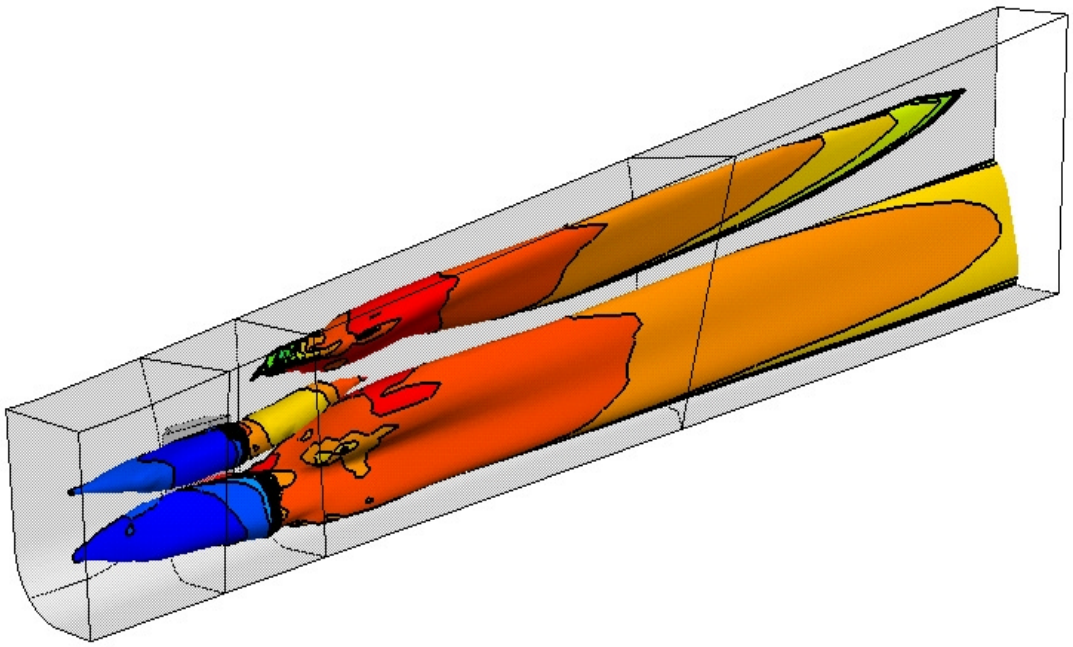
Combustor Solution:

Fuel mass fraction iso-surface colored by temperature



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Combustor Solution

- **Full Navier-Stokes plus finite-rate chemistry solution using *Vulcan*.**
- **Composite five block grid with 1.9×10^5 cells.**
- **6-species 3-step finite-rate gaseous Ethylene model**
- **Inflow profile from Approach solution.**
- **k-ω turbulence model with wall functions; Compressibility correction**
- **Each injector modeled as a single triangular slot with equivalent area, massflow, and momentum. (normal injection).**
- **Flame holding cavity included.**
- **Yields heat & pressure loads for thermal & structural analysis**

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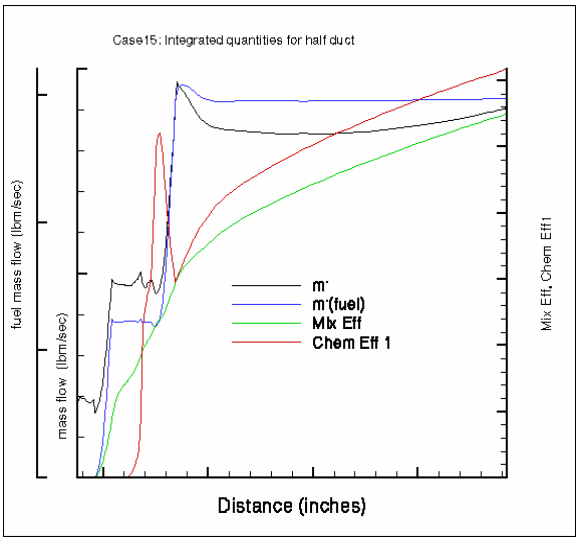
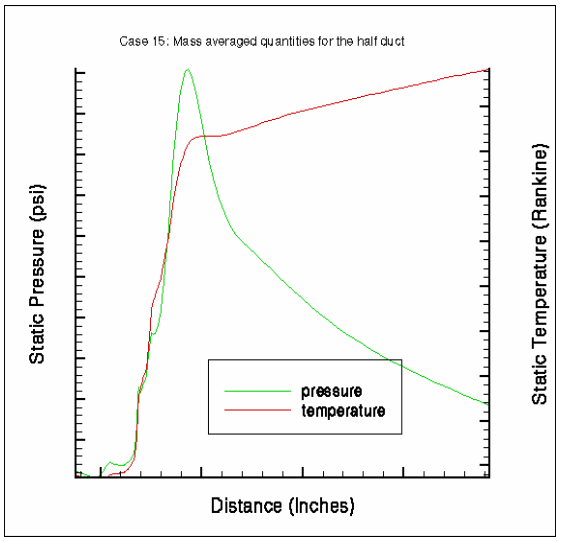
Combustor Solution:
1-D Averaged Quantities





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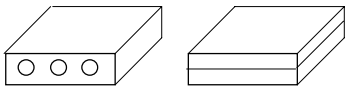
Thermal and Structural Solutions

- **ANSYS—commercial finite element solver.**
- **3-D unstructured grid with 1.3×10^5 nodes and 8.6×10^4 tetrahedra**
- **Temperature dependent material properties for Inconel 625, Titanium β21S**
- **Coolant passages modeled as a bi-layer material**



- **Neglects details of heat conduction around coolant passages, plus structural effects**
- **Some modeling of coolant circuit.**
- **Thermal model yields temperatures from heat loads, coolant system, and material properties**
- **Structural model yields deflections & stresses from pressure & temperature loads**

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Ansys Thermal/Structural Grid

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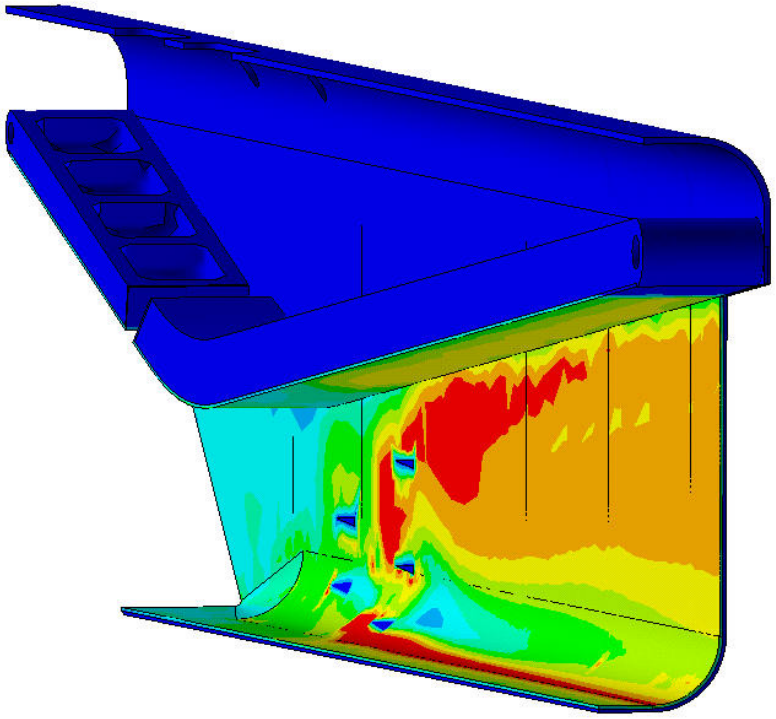
Coupled Thermal Solution



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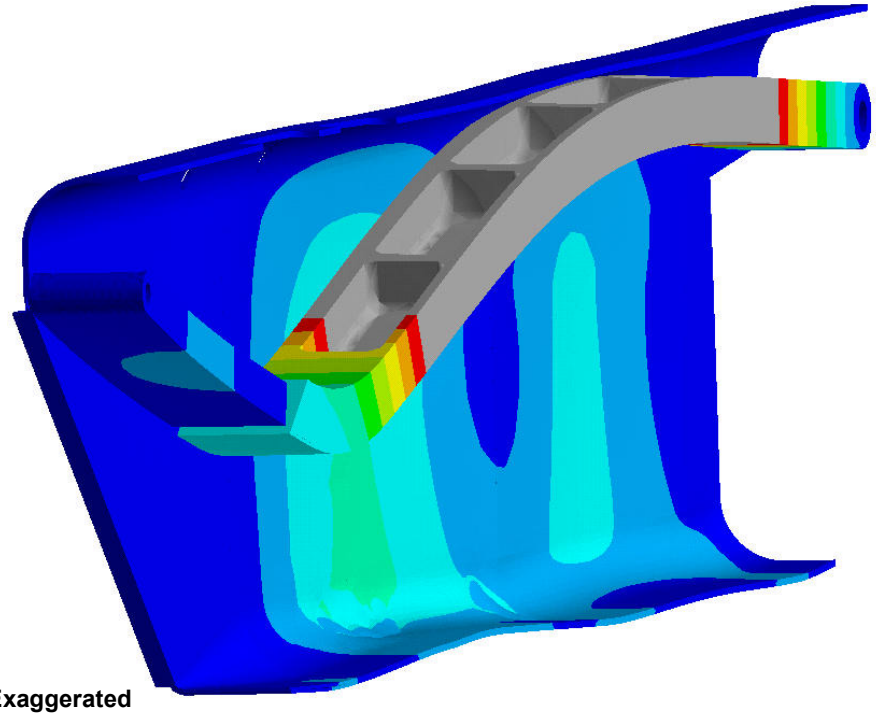
Structural Solution



Deflections Exaggerated

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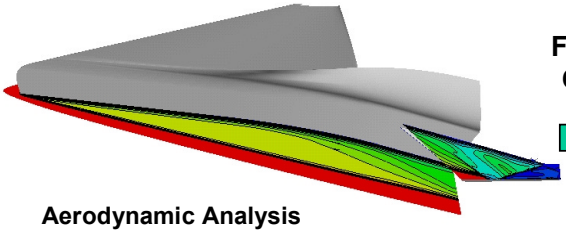
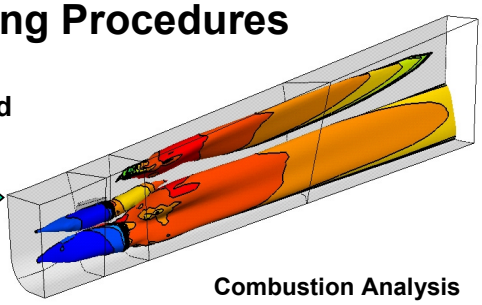
Multidisciplinary Coupling Procedures



Aerodynamic Analysis

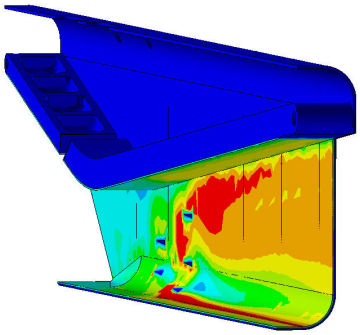
Fluid-Fluid Coupling



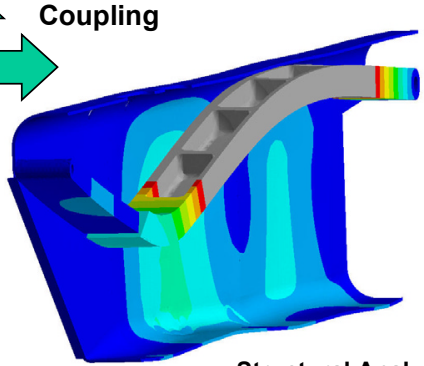
Combustion Analysis

Fluid-Thermal Coupling

Fluid-Structural Coupling



Thermal Solid Analysis



Structural Analysis

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Consistent Multidisciplinary Solutions

- **Fluid-Fluid Coupling: Flow quantities are the same where the Fluid codes meet**
- **Fluid-Thermal Coupling: Heat fluxes & Temperatures are the same where Fluid & Thermal codes meet**
- **Fluid-Structural Coupling: Deflected walls are the same as the Fluid boundaries**

ISTAR Multidisciplinary Simulation: Interpolation & Consistency

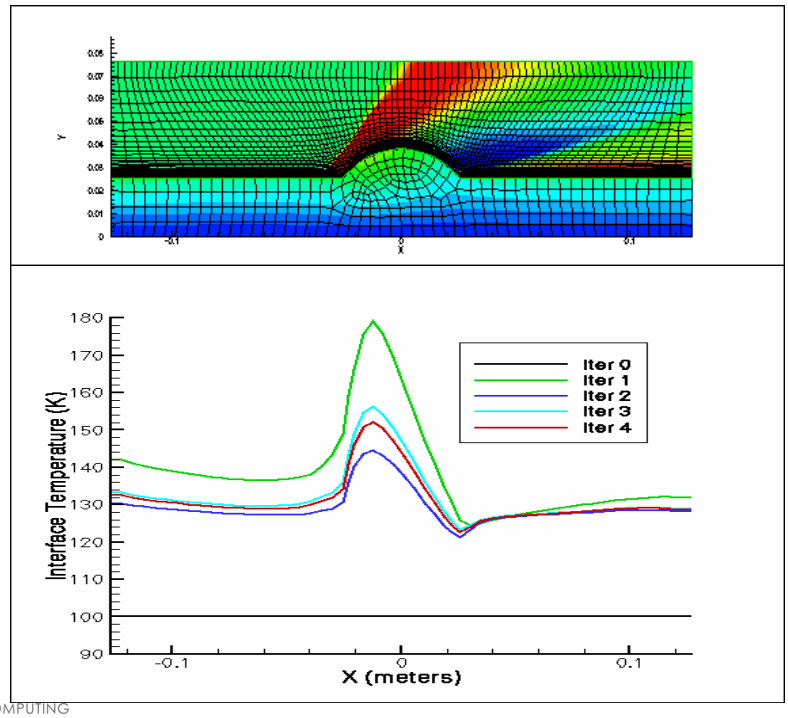
- **Interpolation transfers inflow profiles, thermal & pressure loads, displacements from code-to-code.**
- **One-pass:**

  (Fluid ⇒ Thermal ⇒ Structural)

  Boundary conditions often inconsistent.
- **Consistency achieved with multiple passes:**

  (Fluid ⇔ Thermal ⇔ Structural)

Fluid-Thermal Iteration

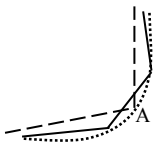


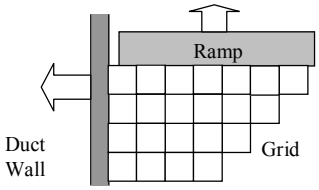
In engine case, L2 Norm of:

$\Delta T = 500\ ^{o}R.$

Challenging Issues in Coupling: Toolkit Specific

- **Robust interpolation between codes on wetted surface**
  - Accept all types of grids and formats.
  - Some tolerance for out of plane target points.
  - Subsetting of source grids.
  - Extrapolation at boundaries.





- **Update fluid grids to include surface deflections**
  - Difficult when deformations, particularly shear deformations, exceed the grid spacing.

Challenging Issues in Coupling: Code Specific

- **Noisy heat fluxes from fluid codes**
- **Code compatibility w.r.t coupling (turbulence models, wall functions?)**

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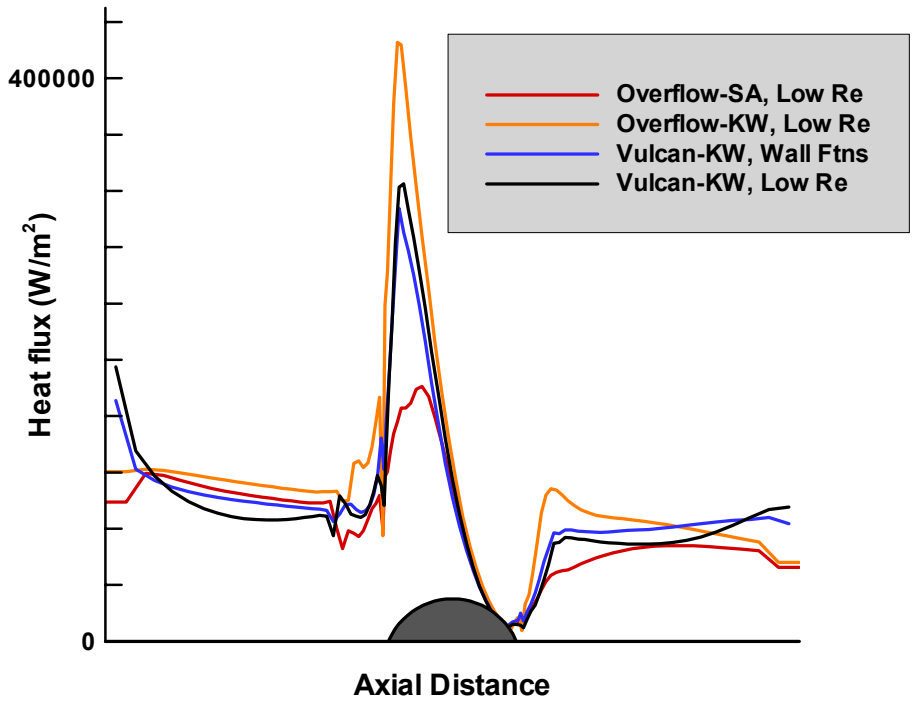
Calculation of Accurate Heat Fluxes



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Benefits & Costs
(Single Discipline vs. Multidisciplinary)

- Cooling system design potentially aided by thermal/fluid calc.
- Computational cost: MD adds 100% of single discipline
- Cost of Setting up MD problem: a toolkit would help (Interpolation++)
- Disparate turn around times:
  thermal & structural time is <1% of fluid & combustion

Summary

- Single discipline simulations coupled into Multidisciplinary simulation.
- Application is Scram design point of ISTAR concept vehicle
- Reveal some code coupling issues and obstacles, costs and benefits